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Leveling

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3.1 Introduction

A coating is applied to a surface by a mechanical force: by a stroke of a brush, by transfer from a roll, by removing the excess with a knife's edge, or by other means. Most of these coating processes leave surface disturbances: a brush leaves brush marks; a reverse roll coater leaves longitudinal striations; knife coating leaves machine direction streak; roll coating leaves a rough surface, when the coating splits between the roll and the substrate; and spraying may produce a surface resembling orange peel.

3.2 Yield Value

These surface disturbances may disappear before the coating is dried, or they may remain, depending on the coating properties and time elapsed between the coating application and its solidification. The surface leveling process is driven by surface tension and resisted by viscosity. Some coatings, especially thickened aqueous emulsions, may exhibit pseudoplastic flow characteristics and may have a yield value: minimum force required to cause the coating to flow (see Figure 3.1). For such coating to level, the driving force (surface tension) must be higher than the yield value. Solution coatings are usually Newtonian (have no yield value) and level rather well. Hot melt coatings solidify fast and may not level adequately. Some typical yield values for various coatings are given in Table 3.1.

Viscosity measurements at very low shear rates are required to determine the yield value. Some of the shear rates experienced in various processes are shown in Table 3.2. A Brookfield viscometer, which operates at shear rates of 0.6 to 24 sec^{-1}, is not suitable for investigating the leveling effects that appear at much lower shear rates. Shear rates experienced during various coating processes are very high, and the viscosity measurements at low shear rates might not disclose coating behavior at these high shear rates.

A yield value of 0.5 dynes/cm^2 produces very fine brush marks, while a yield value of 20 dynes/cm^2 produces pronounced brush marks. The yield stress necessary to suppress sagging is estimated at 5 dynes/

* Deceased.

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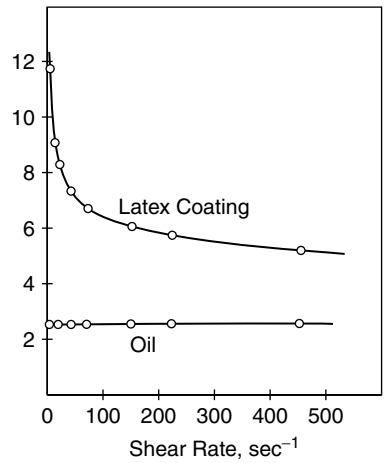

FIGURE 3.1 Viscosity of pseudoplastic emulsion coating as a function of shear rate compared to Newtonian oil.

TABLE 3.1 Yield Values and Thixotropy Ratings for Various Coatings

Coating Type	Yield Value (dynes/cm^2)	Thixotropy Rating
Enamels, glossy	0–30	None to slight
Enamels, semiglossy	50–120	Slight
Flat paints	20–100	Slight to marked
Aqueous wall coatings	10–100	Slight to marked
Metal primers	0–100	None to marked
Varnishes	0	None

TABLE 3.2 Shear Rates for Various Processes

Process	Shear Rate (sec^{-1})
Leveling	0.01–0.10
Pouring if solution	10–100
Mixing	50–1,000
Reverse roll coating	100–10,000
Knife over roll coating	1,000–10,000
Brushing	10,000–50,000
Spraying	10,000–70,000

cm^2, which is not compatible with the best leveling properties. Therefore, to produce both adequate leveling and nonsagging behavior, thixotropic properties must be introduced to a coating.

3.3 Leveling and Viscosity

The driving force of the leveling process is surface tension. The force that resists leveling is viscosity and, to a lesser degree, the elasticity of a coating. To facilitate leveling, therefore, it is desirable to employ coating of low viscosity. Low viscosity coatings, however, cannot always be used. It is difficult to deposit heavy coatings if the viscosity is low. If the coating is applied on a vertical surface, a high viscosity is needed to prevent sagging.

Aqueous coatings are often pseudoplastic: they exhibit a rate-dependent viscosity. They may have a low viscosity (20 to 30 mPa·sec) at high shear rates (10^4 sec^{-1}), such as experienced in roll coating

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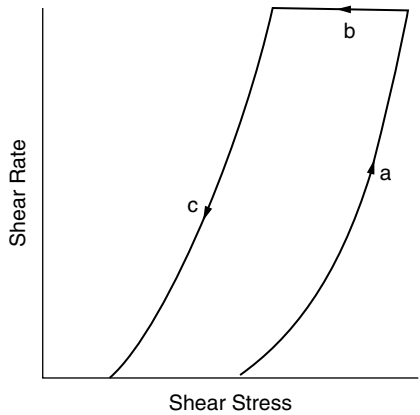

FIGURE 3.2 Thixotropic loop.

operations, and a much higher viscosity (1 to 3 pa·sec) at low shear rates (0.01 to 10 sec^{-1}), prevalent during leveling. Such coatings do not level well because of the high viscosity at low shear rates.

The rheology index is sometimes used as an indicator of the leveling capabilities of a coating. The rheology index is defined as the ratio of high shear rate viscosity to low shear rate viscosity. If the rheology index is one, the coating is Newtonian; if it is larger than one, the coating is dilatant; if it is smaller than one, the coating is pseudoplastic. A large rheology index favors good leveling; it should exceed 0.25 for aqueous systems of acceptable leveling properties.

3.3.1 Thixotropy

Thixotropic behavior of some coatings is utilized to circumvent the dilemma of having a coating of sufficiently low viscosity that levels well and a coating of sufficiently high viscosity that does not sag. Thixotropy is the dependence of viscosity on time. There are coatings that retain a low viscosity for a short period after shearing, thus allowing good leveling, but that thicken fast enough to prevent sagging.

The thixotropic behavior of a coating is usually characterized by the thixotropy loop as shown in Figure 3.2. At the beginning, the coating is sheared at a continuously increasing shear rate, producing curve *a*. Then the coating is sheared at a constant shear rate until constant viscosity (curve *b*) is reached. The shear rate is then gradually decreased, producing curve *c*. The area enclosed by the thixotropy loop indicates the degree of thixotropy: the larger the area, the more pronounced is the thixotropic behavior of the coating. A pseudoplastic coating that exhibits no thixotropy would form no loop, and curve *a* would coincide with curve *c*. Curve *b* would not be formed, because the viscosity is not time dependent in nonthixotropic coatings. Thixotropic behavior is quite common in many aqueous coatings and high viscosity inks, and it is utilized to improve the coatability.

3.4 Leveling and Surface Tension

If the coating contains ingredients of differing surface tension and volatility, a surface tension gradient may be formed during drying, which results in poor leveling.[1] This behavior was observed when a drop of alkyd resin was dried in heptane solution. A high surface tension is created around the outer edges because of a faster solvent evaporation rate in that region. This causes a flow of the solution from the center of the drop, resulting in formation of a doughnut-shaped resin deposit. When xylene is employed as the solvent, the result is the opposite. A region of lower surface tension is produced around the outer perimeter of the drop, resulting in a thicker center of the dried deposit. The addition of a solvent-soluble surface active agent eliminates the formation of the surface tension gradient, resulting in a dried deposit of uniform thickness.

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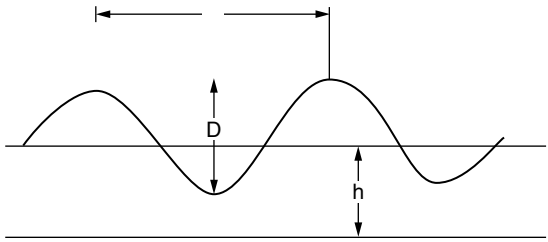

FIGURE 3.3 Profile of coating striation marks.

3.5 Leveling of Brush and Striation Marks

Brush application produces brush marks dependent on the rush fineness. Reverse roll and other roll coaters in which the coating splits between the rolls produce regular longitudinal striation marks in the coating. Knife coaters produce longitudinal streaks caused by the restriction of the flow under the knife by gel and other particles. The geometry of such coating striations or brush marks is shown schematically in Figure 3.3.

According to Orchard's[2] mathematical model of the leveling process, the leveling half-time may be expressed in the following manner:

$$T_{1/2} \propto \frac{\eta L}{\gamma} \frac{\lambda^4}{h^3}$$

where γ is the surface tension and η_L the viscosity (at low shear rate).

The equation states that a low viscosity and a high surface tension favor the rate of leveling. The geometry of the coating (distance between striation marks and the coating thickness) has a very large effect on leveling. Decreasing the distance between the striation or brush marks is very effective in accelerating leveling, as is an increase in coating thickness. It has also been stated by some authors[3] that coating elasticity has a retarding effect on leveling, although the effect is less important than that of viscosity.

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